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Development of a Numerical Damage Index for Critical Evaluation of Mechanical Damage of Corn

Mofazzal H. Chowdhury, Wesley F. Buchele

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EVALUATION of mechanical damage has always been one of the most elusive problems associated with the harvesting, handling, and marketing of corn. Although greatly needed, there is no standard method to describe the quality of corn from the standpoint of physical or mechanical damage.

The most commonly used method of evaluating mechanical damage is the numerical system established by the official grain standards of the US Department of Agriculture in 1916. Since then, hardly any change has been made other than in 1934 when the No. 6 grade was deleted and the maximum limits for damage were relaxed for all grades from No. 1 to 5 (Akiyama 1970).

The numerical grading system was established at a time when corn was shelled at low moisture with minimal damage. The practice of combine corn at high moisture has introduced substantial levels of kernel damage. Although combine-shelled corn contains a small portion of grain fines, the bulk of the kernels are seriously damaged. Such damage includes crushed or chipped kernels and kernels with hairline cracks. The contemporary grading system does not account for all types of mechanical damage. The cracked corn and foreign material referred to in Table 1 is determined by sieving through a 4.76 mm, (12/64-in.) round-hole sieve. Current estimates indicate that the mechanical damage of combined corn ranges between 16.4-79.4 percent in a typical field-harvesting system (Ayres et al. 1972), but only 0.1-3.8 percent was the

cracked corn and foreign material that passed through a 4.76 mm (12/64-in.), round-hole sieve. This indicates that only a fraction of the total mechanically damaged kernels is being accounted for by the present US grading system.

The other method frequently used by research workers (McKibben 1929, Morrison 1955, Saul et al. 1966 and Steel 1967) for critical evaluation of corn damage is visual inspection. They defined mechanical damage as the percentage of the total weight consisting of fines, chipped kernels, and kernels with hairline cracks on the seed coat. Every damaged kernel separated from the sound kernels is given equal weight in the damage analysis, and no consideration is given to the severity of the damage to the kernel. This method of analyzing grain damage does indicate what percentage of kernels are damaged, but does not indicate anything about how badly they are damaged. Because mechanical damage occurs on a continuous scale from hairline cracks and tiny spots of pericarp missing to complete breakage (Figs. 5, 4, 3), the severity of damage should be taken into account while evaluating corn kernel damage.

There has been a need for the development of a better idea than the numerical grading system (Akiyama 1972 and Kaminski 1968), but nothing definite has yet been developed. Chung (1968) suggested the use of optical quality of grain as a dam-

age index, but this has yet to be investigated. Hence, an attempt was made to develop a numerical damage indexing system for qualitative, as well as quantitative, evaluation of kernel damage.

EQUIPMENT AND PROCEDURE

A rubber roller sheller powered by a PTO shaft was used to shell the corn. The rubber roller sheller was designed by Brass (1970). The authors conducted research on the sheller to estimate the effects of the operating parameters of the rubber roller sheller for shelling efficiency, feed rate and kernel damage. The data collected for the above study was also used for the development of the damage index. Further study on this subject should be conducted on samples from conventional combines.

The basic functional components of the rubber roller sheller are the pneumatic primary roller (25 x 24.00-8R Goodyear smooth tread terra-tire), the pneumatic orientation roller (four 4.10/3.50-5 go-kart racing slick tires), and the uni-directional bar concave. The complete picture of the rubber roller sheller is shown in Fig. 1. Power for the shelling unit was transmitted from an agricultural tractor (Oliver 77) through a power takeoff shaft (Fig. 2).

The sheller was operated at four cylinder speeds of 175, 250, 350, and 450 rpm and at four levels of roller inflation pressure of 41.37, 68.95, 96.53 and 124.11 kpa (6, 10, 14, and 18 psi). Three replications of each

TABLE 1. THE USDA GRADE REQUIREMENTS FOR YELLOW CORN, WHITE CORN, AND MIXED CORN (EFFECTIVE OCTOBER 1, 1959)

| Grade * | Minimum test weight per bushel, lb | Moisture, percent | Cracked corn and foreign material, percent | Damaged kernels | |
|---------|------------------------------------|-------------------|--|-----------------|----------------------|
| | | | | Total, percent | Heat-damaged percent |
| 1 | 56 | 14.0 | 2 | 3 | 0.1 |
| 2 | 54 | 15.5 | 3 | 5 | 0.2 |
| 3 | 52 | 17.5 | 4 | 7 | 0.5 |
| 4 | 49 | 20.0 | 5 | 10 | 1.0 |
| 5 | 46 | 23.0 | 7 | 15 | 3.0 |

*A sample grade shall be corn which does not meet the requirements for any of the grades from No. 1 to No. 5, inclusive; or which contains stones; or which is musty, or sour, or heating; or which has any commercially objectionable foreign odor; or which is otherwise of distinctly low quality.

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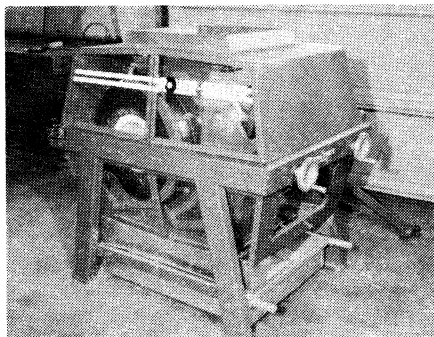


FIG. 1 A complete assembly of the rubber roller sheller.

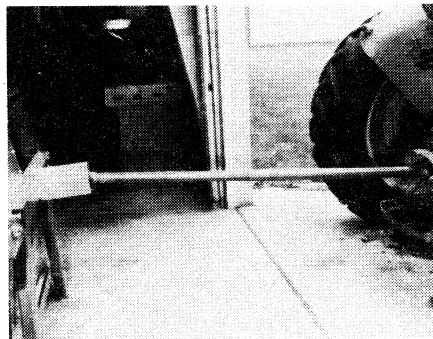


FIG. 2 The primary roller is driven directly from a tractor PTO.

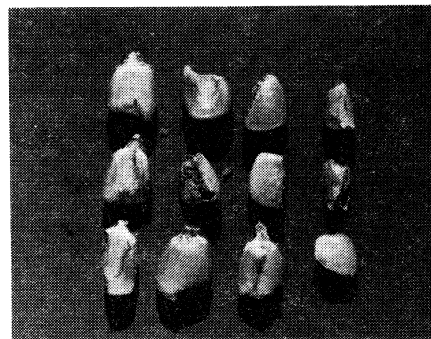


FIG. 3 Severe damage.

treatment resulted in 48 samples at each moisture level. The total number of samples for the five levels of moisture content of 18, 20, 22, 24, and 29 percent (wet basis) resulted in 240 samples. The variety of corn used in this experiment was Pioneer 3369A.

Immediately after every run, one 500-g sample was collected and dried to 15 percent moisture content. The sample was dried in a small drier at room temperature for 24 hrs. Then, by using a Boerner grain divider, a 100-g subsample was divided from the dried sample. The 100-g sample was then passed through a 4.76 mm (12/64-in.) round-hole sieve, and the material passed through the sieve was weighed on a Mettler scale. The remaining kernels from the 100-g sample were soaked in 0.1 percent Fast Green FCF dye for 4 min and placed on a strainer. Excess dye was washed away with running tap water. Dyed samples were spread on paper mats to dry for 24 hr before being visually inspected under a magnifying glass. A kernel was considered damaged if it was broken, cracked, chipped, had bruised pericarp, or any hairline crack on the pericarp. The Fast Green FCF dye stained these damaged parts, thus making inspection easier.

To develop the numerical damage index, the damaged kernels were divided into four categories according to the severity of damage. The

categories are:

- D1 = Broken kernels and the fine material that passed through 4.76 mm (12/64-in.) round-hole sieve.
- D2 = Severe damage — broken, chipped, and crushed kernels (more than 1/3 of the whole kernel missing). (Fig. 3).
- D3 = Major damage — open cracks, chipped, and severe pericarp damage. (Fig. 4).
- D4 = Minor damage — hairline cracks and spots of pericarp missing. (Fig. 5).
- D5 = Whole kernels — did not absorb dye on any part except root tip. (Fig. 6).

The damaged kernels in each category were weighed, and the percentage of damage in each category was calculated on weight basis as follows:

$$d = \frac{X}{W} \times 100$$

where

- d = percentage of total damage
- X = weight of the damaged fraction, g
- W = sample weight, g

The next step was to make a comparative study of the severity of damage of these four damage categories compared with sound kernels. For this purpose, 50 kernels (at random)

from each category were planted in a standard sand bed germination test. Results of the standard germination test for 10 replications of each category are shown in Table 2. The percentage of seed not germinated was calculated and divided by 10 to get a multiplying factor for the different categories according to the severity of damage. For ease of calculation of the damage index, an approximate multiplying factor was decided for the different categories:

| | |
|---------------------------------------|------|
| D1 (Broken kernels and fine material) | = 10 |
| D2 (Severe damage) | = 10 |
| D3 (Major damage) | = 6 |
| D4 (Minor damage) | = 2 |
| D5 (Sound kernels) | = 1 |

The damage index is then calculated by making a visual inspection of a 100 g sample and dividing the sample into five groups. The percentage weight of the different damage categories is then used to evaluate the damage index. The damage index is calculated as:

Damage Index, D.I. =

$$\frac{D_1 d_1 + D_2 d_2 + D_3 d_3 + D_4 d_4 + D_5 d_5}{10} \dots \dots \dots [1]$$

Where

d₁ = percentage weight of D₁ category

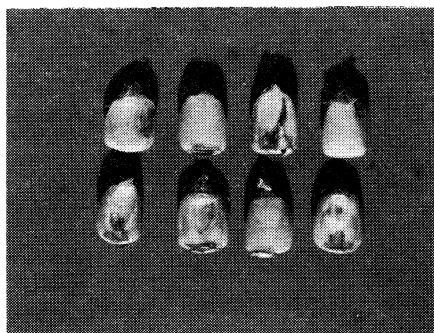


FIG. 4 Major damage.

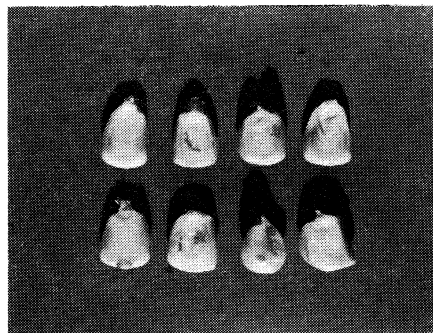


FIG. 5 Minor damage.

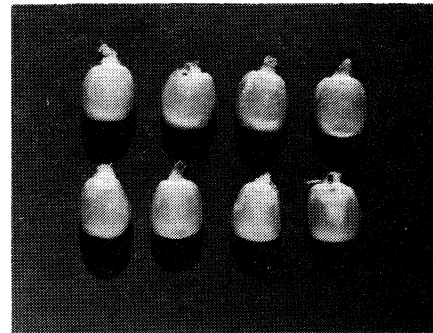


FIG. 6 Whole kernels.

TABLE 2. STANDARD GERMINATION TEST FOR DAMAGED AND SOUND KERNELS (PERCENT GERMINATED)

| | Broken kernels and fine materials (D ₁) | Severe damage (D ₂) | Major damage (D ₃) | Minor damage (D ₄) | Sound kernels (D ₅) |
|-------------------------------------|---|---------------------------------|--------------------------------|--------------------------------|---------------------------------|
| | 0 | 8 | 50 | 86 | 94 |
| | 0 | 8 | 50 | 78 | 84 |
| | 0 | 6 | 46 | 80 | 100 |
| | 0 | 6 | 40 | 74 | 92 |
| | 0 | 6 | 44 | 66 | 82 |
| | 0 | 4 | 36 | 68 | 86 |
| | 0 | 2 | 10 | 80 | 74 |
| | 0 | 6 | 32 | 78 | 92 |
| | 0 | 2 | 43 | 78 | 90 |
| | 0 | 2 | 30 | 78 | 92 |
| Average percentage of germination | 0 | 5.0 | 38.6 | 76.6 | 88.6 |
| Percentage of seed not germinated | 100 | 95.0 | 61.4 | 23.4 | 11.4 |
| Multiplying factor for damage index | 10 | 9.5 | 6.14 | 2.34 | 1.14 |

d₂ = percentage weight of D₂ category

d₃ = percentage weight of D₃ category

d₄ = percentage weight of D₄ category

d₅ = percentage weight of D₅ category

Substituting the values of D₁, D₂, D₃, D₄, and D₅ in equation [1], the equation reduces to:

$$D. I. = \frac{10(d_1 + d_2) + 6d_3 + 2d_4 + d_5}{10}$$

..... [2]

and

D.I. = 10, when the whole lot of the 100-g sample consists of sound kernels (i.e., d₁ = 0, d₂ = 0, d₃ = 0, d₄

= 0, and d₅ = 100). The damage index could have been zero if all the sound kernels would have been germinated. This could be zero for other biological properties such as CO₂ production, storability, and handling ability.

D.I. = 100, when the whole lot of the 100-g sample consists of broken corn, fine material, chipped, and crushed kernels (i.e., d₁ + d₂ = 100, d₃ = 0, d₄ = 0, and d₅ = 0).

In this instance, only the seed viability has been considered for the evaluation of damage index. Other biological factors, such as storability, CO₂ production, and handling ability of corn, have not been considered but could be considered as the basis for a

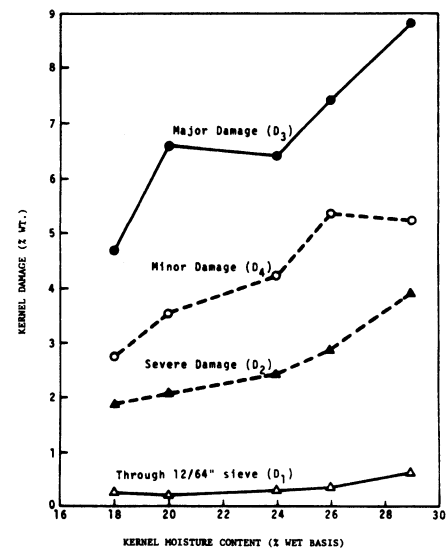


FIG. 7 The relation between percent kernel damage and kernel moisture content for different categories of damage.

damage index. Indeed, the damage index is related to some biological properties of the grain (germination, in this instance). A universal numerical damage index can be established for corn and other grains if the other biological factors are also taken into account. It will be easier to establish a universal numerical damage index if, by studying the other biological factors, a close multiplying factor is found for these categories.

RESULTS AND DISCUSSION

Fig. 7 shows the different categories of kernel damage at various kernel moisture contents (w.b.). Among

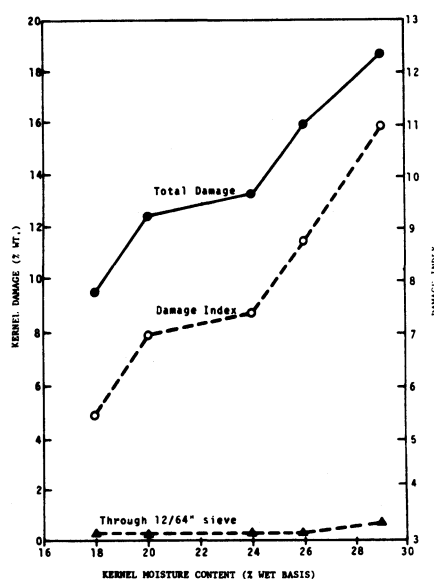


FIG. 8 The relation between kernel moisture content and total mechanical damage, USDA damage grading and the Damage Index.

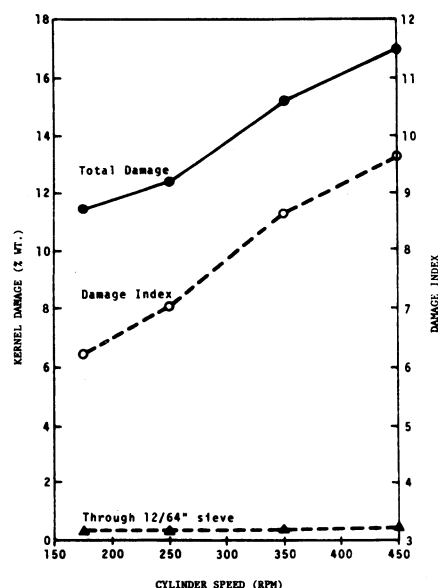


FIG. 9 The relation between cylinder speed and total mechanical damage, USDA damage grading and the Damage Index.

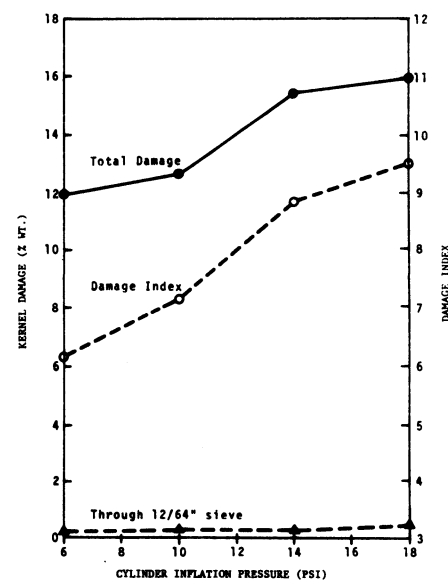


FIG. 10 The relation between cylinder inflation pressure and total mechanical damage, USDA damage grading and the Damage Index.

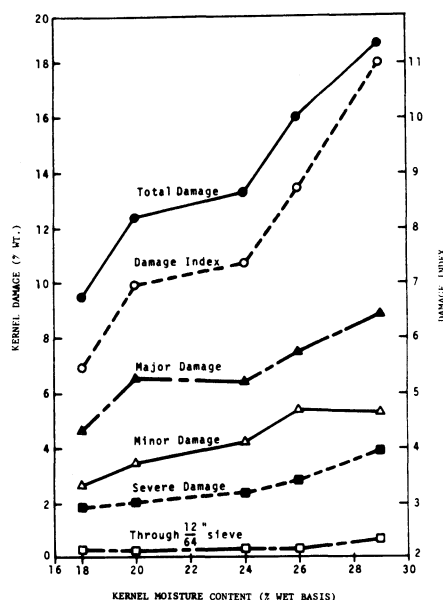


FIG. 11 The relation between kernel moisture content and total mechanical damage, damage index, major, minor and severe damage and USDA mechanical damage grading.

these categories, only the D1 category of damage, which is cracked corn and foreign material, is taken into account by the present USDA grading system for corn. As far as mechanical damage is concerned, the other categories, D2 through D4, goes as unaccounted damage. Indeed, only a fraction of the total mechanically damaged kernels are being accounted for by the present USDA grading system.

Fig. 11 shows the relationship of the percentage of total damage, damage index, and the different categories of kernel damage at various kernel moisture contents. Although the percentage of total damage does include all the damaged kernels, it does not account for the severity of damage of the individually damaged kernels. On the other hand, the damage index does take into account all the damaged kernels, and, at the same time, the severity of damage of the individual kernels. This is indicated by the fact that the damage in-

dex curve follows the percentage of total mechanical damage curve closely for kernel moisture content (Fig. 8), cylinder speed (Fig. 9), and cylinder inflation pressure (Fig. 10). Thus, the numerical damage index does give a better and more complete picture of the total damage situation than do the individual damage categories. The numerical damage index does serve the purpose of qualitative, as well as quantitative evaluation of grain damage.

Analysis of variance were made for different categories of damaged corn kernels and the damage index. The analysis of variance in Tables 3, 4, 5, and 6 indicates that the variables (kernel moisture content, cylinder speed, and cylinder inflation pressure) were not uniformly significant for the different categories of damaged corn kernels. Kernel moisture content was the only variable that was highly significant (at the 1 percent level) for the different categories of damaged corn kernels.

Cylinder inflation pressure was highly significant (at the 1 percent level) for cracked corn, foreign material (Table 3), and severe damage (Table 4). It also was significant at the 5 percent level for major damage (Table 5), but insignificant for minor damage (Table 6).

Similarly, the cylinder speed was highly significant (at the 1 percent level) for severe damage (Table 4) and

major damage (Table 5). It also was significant at the 5 percent level for cracked corn, foreign material (Table 3), and minor damage (Table 6).

Contrary to the inconsistencies found in the level of significance in Tables 3, 4, 5, and 6, the data in Table 7 indicated that all the variables were highly significant (at the 1 percent level) for the damage index. Kernel moisture content, cylinder inflation pressure, and cylinder speed were all highly significant (at the 1 percent level) for the damage index.

A numerical damage index can be a more effective measure of mechanical damage than either the method currently established by the Official Grain (Corn) Standards of the United States Department of Agriculture or the method (total percentage damage) used by the research workers for the evaluation of mechanically damaged kernels.

ADVANTAGES OF THE NUMERICAL DAMAGE INDEX

1 The damage index represents both quantity (percentage) and quality (severity) of the damaged kernels.

2 The damage index evaluates by using the relative biological properties of different categories of damaged kernels (germination, in this instance).

3 Different consumers can devel-

TABLE 3. ANALYSIS OF VARIANCE FOR CRACKED CORN AND FOREIGN MATERIAL

| Source | Sum of squares | Degrees of freedom | Mean square | F value |
|-----------------|----------------|--------------------|-------------|---------|
| MC | 1.85 | 4 | 0.46 | 9.66** |
| PSI | 0.85 | 3 | 0.28 | 5.93** |
| RPM | 0.52 | 3 | 0.17 | 3.63* |
| MC*PSI | 1.01 | 12 | 0.08 | 1.76 |
| MC*RPM | 0.56 | 12 | 0.04 | 0.97 |
| PSI*RPM | 0.44 | 9 | 0.04 | 1.02 |
| Residual | 1.73 | 36 | 0.04 | |
| Corrected total | 7.00 | 79 | 0.08 | |

**Significant at 1 percent level.

*Significant at 5 percent level.

TABLE 4. ANALYSIS OF VARIANCE FOR SEVERE DAMAGE

| Source | Sum of squares | Degrees of freedom | Mean square | F value |
|-----------------|----------------|--------------------|-------------|---------|
| MC | 45.00 | 4 | 11.25 | 11.79** |
| PSI | 49.04 | 3 | 16.34 | 17.14** |
| RPM | 26.29 | 3 | 8.76 | 9.18** |
| MC*PSI | 9.04 | 12 | 0.75 | 0.79 |
| MC*RPM | 10.41 | 12 | 0.86 | 0.90 |
| PSI*RPM | 9.61 | 9 | 1.06 | 1.11 |
| Residual | 34.33 | 36 | 0.95 | |
| Corrected total | 183.75 | 79 | 2.32 | |

**Significant at the 1 percent level.

*Significant at the 5 percent level.

TABLE 5. ANALYSIS OF VARIANCE FOR MAJOR DAMAGE

| Source | Sum of squares | Degrees of freedom | Mean square | F value |
|-----------------|----------------|--------------------|-------------|---------|
| MC | 149.28 | 4 | 37.32 | 11.86** |
| PSI | 40.66 | 3 | 13.55 | 6.31* |
| RPM | 69.03 | 3 | 23.01 | 7.31** |
| MC*PSI | 24.71 | 12 | 2.05 | 0.65 |
| MC*RPM | 72.04 | 12 | 6.00 | 1.90 |
| PSI*RPM | 39.18 | 9 | 4.35 | 1.38 |
| Residual | 113.22 | 36 | 3.14 | |
| Corrected total | 508.19 | 79 | 6.43 | |

**Significant at the 1 percent level.

*Significant at the 5 percent level.

TABLE 6. ANALYSIS OF VARIANCE FOR MINOR DAMAGE

| Source | Sum of squares | Degrees of freedom | Mean square | F value |
|-----------------|----------------|--------------------|-------------|---------|
| MC | 82.45 | 4 | 20.61 | 5.98** |
| PSI | 8.50 | 3 | 2.83 | 0.82 |
| RPM | 36.82 | 3 | 12.27 | 3.56* |
| MC*PSI | 37.05 | 12 | 3.08 | 0.89 |
| MC*RPM | 29.62 | 12 | 2.46 | 0.71 |
| PSI*RPM | 31.53 | 9 | 3.50 | 1.01 |
| Residual | 124.09 | 36 | 3.44 | |
| Corrected total | 350.09 | 79 | 4.43 | |

**Significant at the 1 percent level.

*Significant at the 5 percent level.

op their own index by using different biological properties.

4 This technique can be used for the development of numerical indices for other grains such as beans, wheat, and rye.

5 Critical comparison can be made between harvesting machines or between adjustment of the harvesting machines.

6 The reading of a damage meter, if and when one is developed, should compare favorably with the damage index. The damage index can be read on a continuous scale from 10 (no damage) to 100 (completely damaged for germination), and for other uses, it can be read from 0 (no damage) to 100 (completely damaged). The different corn consumers can set their own range of damage index (on the damage meter) that will best serve their purpose.

7 This will reduce the human error

to a minimum while evaluating grain damage.

SUMMARY AND CONCLUSION

A numerical damage index has been developed by using one of the many biological properties of the grain, germination in this instance, for critical evaluation of mechanical damage of corn. Further research considering such factors as storability, CO₂ production, and handling ability of the grain should be conducted to establish a universal damage index. A universal numerical damage index would be a standard that the entire corn industry could use in determining the quality of corn.

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TABLE 7. ANALYSIS OF VARIANCE FOR DAMAGE INDEX

| Source | Sum of squares | Degrees of freedom | Mean square | F value |
|-----------------|----------------|--------------------|-------------|---------|
| MC | 27647.75 | 4 | 6911.93 | 18.97** |
| PSI | 14061.24 | 3 | 4687.08 | 12.86** |
| RPM | 14269.40 | 3 | 4756.46 | 13.05** |
| MC*PSI | 2381.22 | 12 | 198.43 | 0.54 |
| MC*RPM | 5835.49 | 12 | 486.29 | 1.33 |
| PSI*RPM | 5180.18 | 9 | 575.57 | 1.57 |
| Residual | 13114.52 | 36 | 364.29 | |
| Corrected total | 82489.83 | 79 | 1044.17 | |

**Significant at 1 percent level.